Chapter 5

Fuels for Cement Kilns

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1. INTRODUCTION

By common definition a fuel is any material that liberates heat when it reacts with oxygen. In practice, however, only those materials which ignite at moderate temperatures burn with comparative rapidity are obtainable in quantity at reasonable prices are regarded as fuels.

According to their physical state fuels are divided into 3 main groups, i.e. solid, liquid and gaseous. All 3 are employed in the cement industry. Originally coal was used almost exclusively. Around 1960 the conversion to oil and gas firing began and proceeded quickly because these two fuels had become sensibly cheaper than coal, and furthermore they were much easier to handle. However, after 1973 oil (and gas) prices rose again steeply and soon surpassed coal by far. Plants in countries without own deposits of oil or gas began to return to coal, and by now most of them are back again to nearly 100 % of coal firing. Fig. 1 shows the consumption of different fuels in the cement industry of Switzerland, a country which has neither coal nor oil of her own. For countries which dispose of oil (or gas) deposits the return to coal is not so urgent, of course, but on the whole coal is gaining ground world-wide as can be seen e.g. from figures 2 and 3 which show the development in the "Holderbank" Group since 1974.

Fig. 1   Consumption of Coal and Fuel Oil in the Swiss Cement Industry from 1959-1985
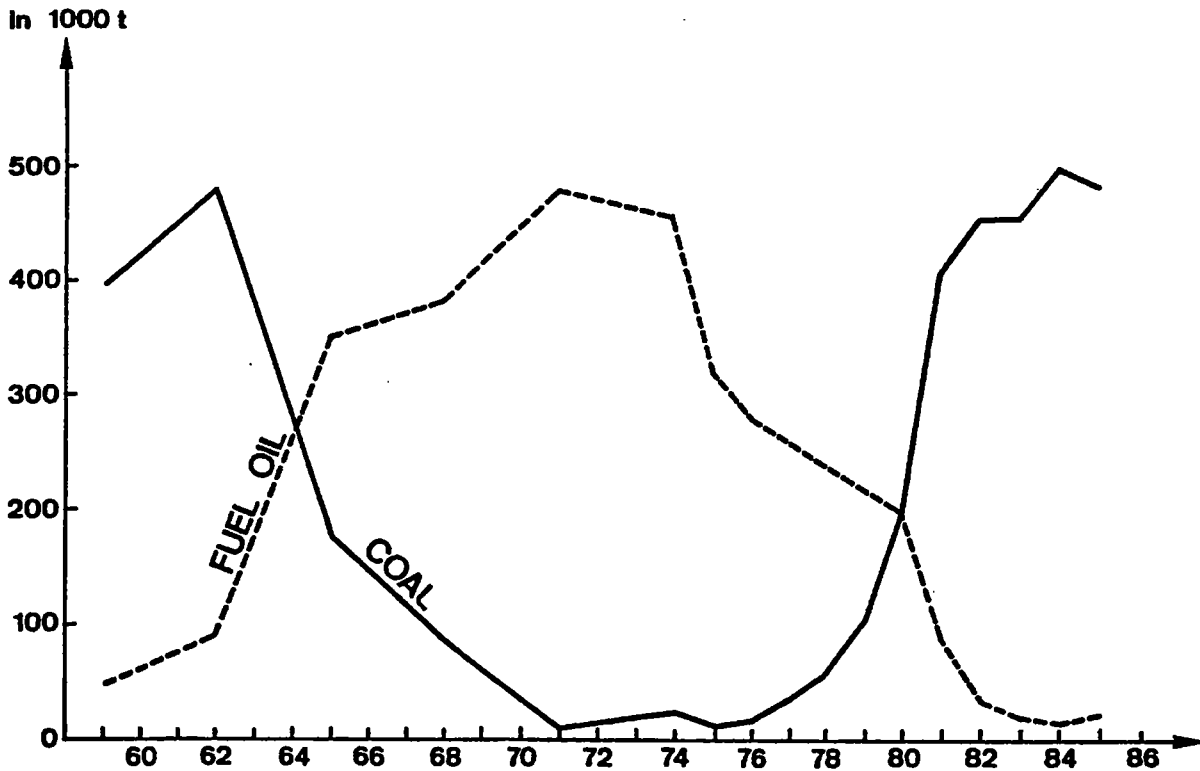
Fig. 2   **Percentage of Clinker Produced with Different Types of Fuel**
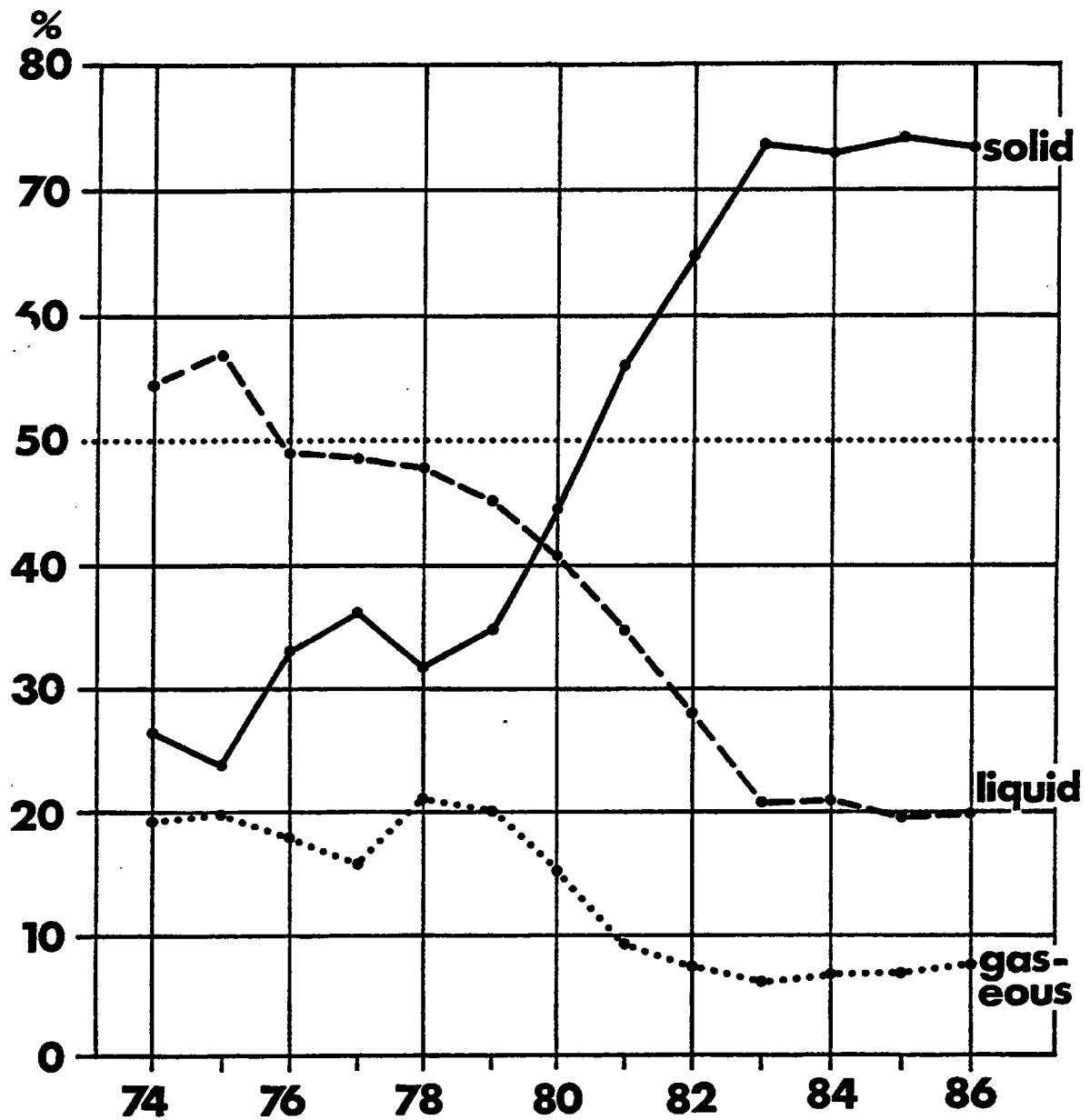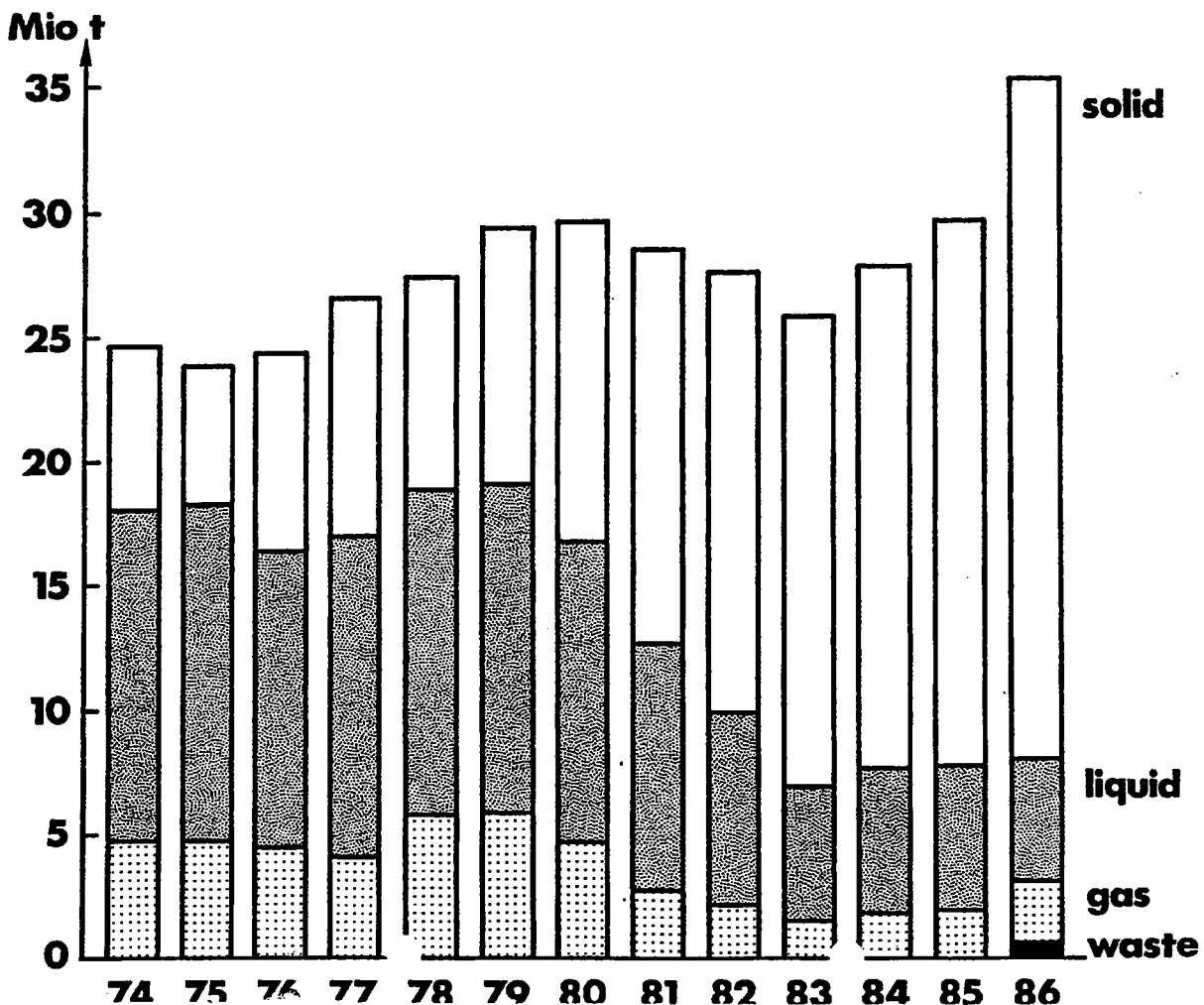
Fig. 3   Quantity of Clinker Produced with Different Types of Fuel

2.   GENERALITIES

2.1   CHEMICAL COMPOSITIONS

All ordinary fuels consist mainly of carbon and hydrogen accompanied by minor amounts of nitrogen, oxygen, sulfur and sometimes inorganic minerals. For example, table 1 shows the analyses of the mostly used fuels on a dry, mineral-free basis and without inert components of natural gas like N_2 and CO_2.

Table 1:   Ultimate analyses of fuels (weight percent)

	bituminous coal	fuel oil	natural gas
C	88 - 90	83 - 87	75 - 77
H	4 - 5	11 - 13	23 - 25
O	3 - 4	0.1-0.4	traces
S	1 - 2	1 - 3	traces

Appreciable amounts of minerals which form ashes after combustion occur only in solid fuels and shall be discussed in chapter 3.5.

Sulfur, although a minor component of fuels is of particular importance because of its effects on clinker quality and, above all, the environment. Furthermore, owing to its volatility, it can accumulate in certain parts of the kiln system and form build-ups and rings. Therefore it is absolutely necessary to supervise closely the sulfur contents of both raw mix and fuel. Depending on the raw mix composition and on kiln conditions (temperature, atmosphere) the clinker can absorb considerable quantities of sulfur in the form of sulfates. When its capacity is exceeded the excess sulfur is emitted by the stack as SO_2 which can have detrimental effects on organisms and buildings. Therefore in most industrialised countries the authorities have restricted the emission of SO_2 and in some cases even demand monitoring of emissions.

2.2   HEAT OF COMBUSTION

The carbon and hydrogen contents of the fuels determine their most important property, namely their heat of combustion or calorific value. Chemically speaking combustion is nothing else but oxidation. The elements of the fuel, mainly carbon and hydrogen, combine with oxygen from the air and a certain amount of energy is set free as heat. The heat is measured in

♦   Joule (J) (International Standard Unit)

♦   calorie (car) (no longer valid but still widely used)

♦   British Thermal Unit (BTU) (United Kingdom, USA etc.)

The conversion factors are

♦   1 cal = 4.187 J

♦   1 BTU = 1055 J

For the requirements of the cement industry a larger unit is more suitable i.e. the Mega-Joule (MJ)

♦   1 MJ = 106 J

The heat generated per unit weight of fuel is called specific "heat of combustion" or "calorific value". For example, 1 kg of carbon will combine with 2.67 kg of oxygen to form 3.67 kg of CO_2, releasing 33.9 MJ of heat:

1kg C + 2.67kg O_2 → 3.67kg CO_2 + 33.9 MJ
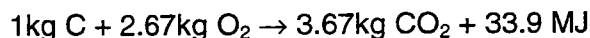
Accordingly the calorific value of carbon is 33.9 MJ/kg.

The calorific value is normally calculated for complete combustion to the highest possible state of oxidation. If not sufficient oxygen is present toxic CO will be formed with much less heat development:

1kg C + 1.33 kg O_2 → 2.33kg CO + 10.0 MJ
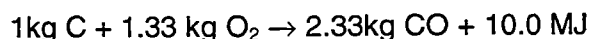
This means that the emission of carbon monoxide is not only a pollution of the atmosphere but also a waste of energy.

For hydrogen one obtains for the formation of water vapour

1kg H_2 + 8kg O_2 → 9kg H_2O + 119.9 MJ
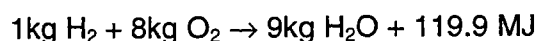
This is called the 'net calorific value'. By condensation of the vapour another 20.3 MJ would be released bringing the total heat development of the reaction to 140.2 MJ. This is the 'gross calorific value'. Of course, for cement kilns only the net values are important because the flue gases leave far above 100°C and therefore the heat of condensation of the water vapour cannot be utilised. Nevertheless in some countries, including the US, the gross calorific value is generally used.

For conversion from gross (G) to net (N) heats of combustion (MJ/Kg) the following formula is valid:
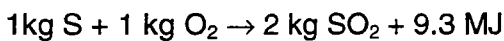
$$N = G - (W_B + W_M) . H_C$$

where W_M stands for the moisture content of the fuel, W_B for the water generated by combustion (all in kg), and H_C for the heat of condensation of water vapour which is 2.26 MJ/Kg.

The contribution of sulfur to the calorific value of fuels is very small:

$$1 kg \ S + 1 \ kg \ O_2 \rightarrow 2 \ kg \ SO_2 + 9.3 \ MJ$$

Besides MJ/kg other units for calorific values are still in use such as

♦ J/g (or kJ/kg)

♦ cal/g (or kcal/kg)

♦ BTU/lb (British Thermal Units per pound)

For gaseous fuels the calorific values usually refer to units of volume under standard conditions (0°C, 760 mm Hg) instead of mass (Nm^3 = cubic meter or cf = cubic foot. 1 Nm^3 = 35.31 cf). The conversion factors of these units are listed in table 2.

Table 2: Conversion factors for calorific values

a) Units for solid and liquid fuels			
	J/g	cal/g	BTU/lb
J/g	1	0.2388	0.4299
cal/g	4.187	1	1.800
BTU/lb	2.326	0.5555	1
b) Units for gaseous fuels			
	kJ/Nm^3	$kcal/Nm^3$	BTU/cf
kJ/Nm^3	1	0.2388	0.0268
$kcal/Nm^3$	4.187	1	0.1122
BTU/cf	37.25	8.896	1

Typical calorific values of the main fuels employed in the cement industry are shown in table 3.

Table 3: Net calorific values of various fuels

a) solids + liquids	MJ/kg	cal/g	BTU/lb
bituminous coal (dry, mineral-free)	33 - 35	7800 - 8400	14100 - 15200
heavy fuel oil	40 - 41	9600 - 9900	17300 - 17800

b) gaseous	MJ/Nm	kcal/Nm3	BTU/cf
natural gas	34 - 38	8000 - 9000	900 - 1000

From the foregoing it can be inferred that the calorific value of a fuel may be calculated from its elementary composition. However, the energy to break up the chemical compounds of the fuel has to be deducted. In general, this is not known with sufficient accuracy. Therefore the direct determination of the heat of combustion by calorimetric methods is to be preferred. It is simple and quick and requires no special skill if a modern calorimeter is available. Fuel prices depending directly on calorific values frequent checks are to be strongly recommended. Owing to the tremendous heat requirements of a cement kiln even small variations of the calorific values may become very costly.

3.   COAL

3.1   FORMATION AND CLASSIFICATION OF COALS

Collier's Encyclopedia defines coal as a "combustible, sedimentary rock formed of vegetable matter by physical and chemical alteration through geologic processes". The first intermediate product of these processes is peat which is not yet considered as coal. Then follows lignite (or brown coal) several types of bituminous coal, and finally anthracite. During this transformation the carbon content and with it the calorific value increase continuously while the volatile matter (mainly hydrocarbons), decreases. Thus coals are classified according to their contents of volatile matter and/or their calorific value. For example, table 4 shows the ASTM classification (Standard Specification D 388 - 66).

Table 4   Classification of Coals by Rank

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, percent (Dry, Mineral-Matter-Free Basis)		Calorific Value Limits, Btu per pound (Moist,[a] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	
I. Anthracitic	1. Meta-anthracite	98	...	...	2	...	...	nonagglomerating
	2. Anthracite	92	98	2	8	...	...	
	3. Semianthracite[c]	86	92	8	14	...	...	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	...	...	Commonly agglomerating[b]
	2. Medium volatile bituminous coal	69	78	22	31	...	...	
	3. High volatile A bituminous coal	...	69	31	...	14 000[d]	...	
	4. High volatile B bituminous coal	...	...	...	...	13 000[d]	14 000	
	5. High volatile C bituminous coal	...	...	...	...	11 500	13 000	agglomerating
						10 500	11 500	
III. Subbituminous	1. Subbituminous A coal	...	...	...	...	10 500	11 500	nonagglomerating
	2. Subbituminous B coal	...	...	...	...	9 500	10 500	
	3. Subbituminous C coal	...	...	...	...	8 300	9 500	
IV. Lignitic	1. Lignite A	...	...	...	...	6 300	8 300	
	2. Lignite B	...	...	...	...	...	6 300	

[a] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.
[a] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.
[c] If agglomerating, classify in low-volatile group of the bituminous class.
[d] Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.
[b] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile C bituminous group.

3.2   ANALYSIS

Proximate Analysis

Proximate Analysis covers the determination of moisture, volatile matter, fixed carbon, and ash by determining the weight losses at certain temperatures. For example ASTM-Standard D 3172 prescribes

♦   for moisture 107°C in air

♦   for volatile matter 950°C with exclusion of air(covered crucibles)

♦   for fixed carbon 750°C in air The residue in ash.

Proximate analysis is simple and fairly quick. Together with the calorific value and sulfur content it is sufficient for all practical purposes.

Ultimate Analysis

Ultimate Analysis determines the elementary composition. It requires special equipment and can only be carried out in laboratories with appropriately trained personnel.

Sulfur

Sulfur is analysed by ignition and subsequent determination of SO2 in the combustion gases by infrared absorption or colorimetry.

Chlorine

Chlorine can be determined in the liquid from the calorimetric bomb by titration with silver nitrate.

Ash composition

Ash composition which is important for correct calculation of the raw mix (see chapter 3.5) is analysed by the same methods as other raw materials.

3.3 VOLATILE MATTER

Not all types of coal are equally suitable for cement kilos. If the volatile contents are too low ignition of the coal particles is delayed and the flame becomes too long. On the other hand, high volatile contents increase the risk of self-ignition and explosions. For a long time about 20 % of volatile matter was considered an acceptable compromise, and preferably bituminous coal of that composition was used, or, if that was not available, a corresponding mixture of coals with higher and lower volatile contents. In the meantime engineers have learned to master the risk of self-ignition and explosions and brown coal containing 50 % of volatiles or even more can be employed.

3.4   GRINDING AND DRYING

Besides a certain content of volatile matter the fineness of the coal dust is of prime importance for the generation of a good flame in the kiln. In fact, a lack of volatiles can to a certain extent be compensated for by finer grinding of the coal as can be seen on fig. 4:

Fig. 4   Required fineness of coal as a function of volatile content (Sieve numbers indicate mesh openings in mm)
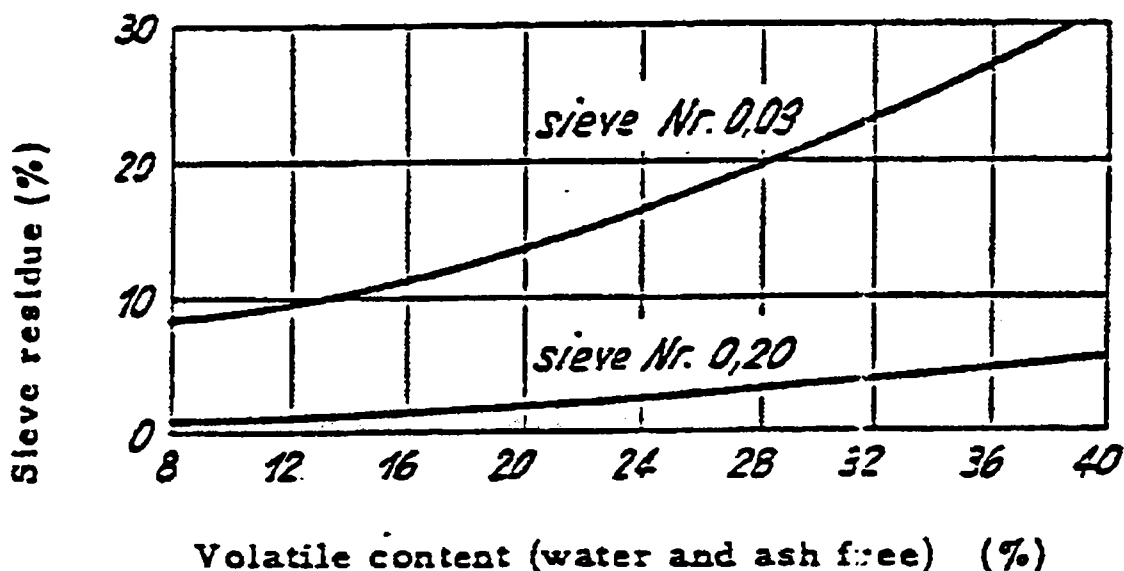
Grinding is generally combined with drying of the coal. This drying should not go too far because completely dry coal could be difficult to ignite. In the absence of water the reaction of carbon with oxygen is very sluggish. 1 - 1.5 % of residual moisture in the coal will accelerate the reaction sufficiently. The exact drying temperature for a certain coal can be determined in the laboratory by establishing the desiccation curve, i.e. residual water as a function of the temperature.

3.5   ASH CONTENT

It has already been mentioned that coal contains mineral components which leave solid remainders after combustion, the ash. Bituminous coal which is generally used for clinker burning gives a siliceaous ash in the form of molten drops. These are carried away by the flame gases and finally settle on the clinker being formed. There is thus a higher SiO_2-concentration on the surface of the kiln charge. Depending on how far the ash drops are carried into the kiln they will be more or less assimilated with the clinker granules. Due to the deposition of ash drops rich in silica on the kiln charge there is a local lack of CaO. Here only belite can be formed and thus the deposition of ash leads to typical belite streaks in the clinker as shown in chapter 13.2.3.5, plate 19.

Because the coal ash is incorporated into the clinker it is absolutely necessary to take it into account when calculating the raw mix. The following example may serve to demonstrate this. Suppose raw materials and ash have the compositions listed in table 5 a) and the coal required for clinker burning leaves 2 % of the raw mix weight as ash. To produce a clinker with 55 % C3S the raw mix shown in the first column of table 5 b) would be required.

If the coal ash is not taken into account the calculation for 55 % C_3S will give the raw mix of the second column. After incorporation of the coal ash the C_3S - content of the clinker would come down to only 39 %.

Table 5: Consequences of neglect of coal ash at raw mix calculations

a) Analyses of raw materials and ash (%)

	Limestone	Clay	Sand	Coal ash
L.o.i.	42.2	12.5	16.7	---
SiO_2	3.1	52.2	59.4	42.9
Al_2O_3	0-9	15.6	1.5	20.6
Fe_2O_3	0.6	13.2	3.0	22.4
CaO	52.6	2.4	17.2	8.2

b) Raw mix calculated for 55 % C_3S (%)

	with ash	without ash
Limestone	79.2	77.9
Clay	15.0	17.8
Sand	5.8	4.3
Coal ash	2.0	

c) Clinker analyses (%) after absorption of coal ash

SiO_2	22.2	22.8
Al_2O_3	5 4	6.0
Fe_2O_3	4 7	5.1
CaO	65.6	63.9
Tricalciumsilicate C_3S (%)	55.0	39.0

4. FUEL OIL

4.1 COMPOSITIONS AND CLASSIFICATION

Fuel is one of the products of the refining of petroleum. Petroleum or crude oil is a liquid found in subterranean deposits. Chemically it is a complex mixture of hydrocarbons which range from molecules containing one carbon atom to more than ninety. In addition sulfur, nitrogen, oxygen and traces of some metallic elements appear in varying amounts in the molecules.

By distillation and other processes ("refining") the crude oil is split up into a large number of different products, among them several types of fuel oil. These are classified according to their density, viscosity, and other properties. For cement kiln firing only the heavy quality is used, designated as Bunker C or No. 6 Fuel Oil in the USA. In Germany and Switzerland it is called Heavy Fuel Oil (Schweres Heizöl = Heizöl S).

Heavy fuel oil consists primarily of the residue from distillation and other refinery processes, such a thermal cracking, visbreaking, etc., with the addition of various diluents to meet various specification limits for the viscosity, density and sulphur content of the finished product.

The chemical and physical properties of heavy residual fuels are dependent both on the origin of the crude oil and on the processing conditions in the refinery. The main properties of fuel oil derived from petroleum are subject to certain standards. For example, table 6 shows the German Standard DIN 51603.

Table 6: Requirements for heavy fuel oil as per German Standard DIN 51603

| Flashpoint in closed cup : min	°C	65;100
Kinematic viscosity : max	mm^2/s(cSt)	at 50°C: 450 at 100°C: 40
Pour point :	°C	no specifications
Conradson carbon residue: max	% mass	15
Sulphur content: max	% by mass	2.8
Water content, not removable: max	% mass	0.5
Sediment content: max	% mass	0.5
Calorific value: min	MJ/kg	39.8
Ash (oxide ash): max	% mass	0.15

4.2 DENSITY

The density of fuel oil is strongly dependent on temperature. For 1°C increase in the temperature of heavy oil the density decreases, on average, by 0.63 %. Therefore the density must always be given with a reference temperature, usually 15°C (d_{15}). There are statistical relationships between density and other properties of fuel oil, specially the calorific value. Being relatively easy to measure density is suitable for regular and frequent quality control.

4.3 VISCOSITY

Apart from the calorific value viscosity is the most important property of fuel oils. Both pumping and atomisation require certain viscosities. These can be obtained by heating the oil because the viscosity depends strongly on temperature. Fig. 5 shows this together with the atomisation range and pumping limits. It can be seen that for optimal atomisation the heavy fuel oil must be heated to about 120°C. The oil temperature has to be strictly controlled because even small variations would cause marked changes of viscosity and thereby also atomisation.

Fig. 5   **Kinematic Viscosity of Fuel Oil as a Function of Temperature**
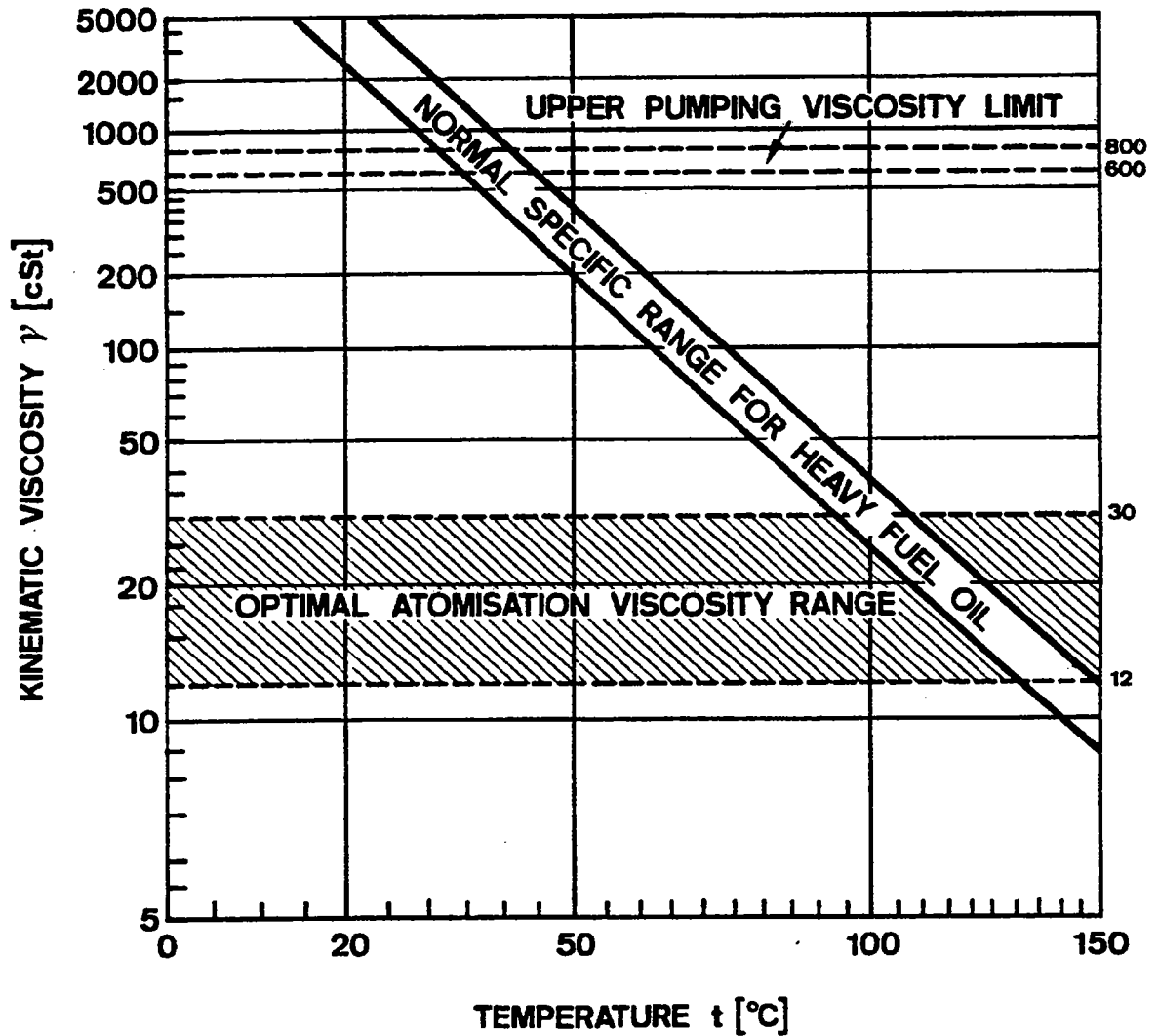
The International Standard Unit of viscosity is the Poise (P):

$$1P = 10^{-1} \frac{N.s}{m^2}$$

It is called "dynamic viscosity". The ratio of dynamic viscosity to density is designated as "kinematic viscosity", usually measured in centistokes (cSt). In practice empirical units are often employed such as Redwood-seconds in Great Britain, or Saybolt seconds ("Universal" and "Furol") in the USA. Table 7 contains a comparison of the different viscosity scales.

Table 7: Comparison of viscosity units

Saybolt seconds		Redwood	cSt
Universal	Furol	seconds	
100	15	89	20.6
160	20	145	34.2
300	32	292	65.0
500	52	438	108
800	81	800	173
1500	150	1400	324
3000	300	2800	648

4.4 POUR POINT

Some fuel oils show an anomaly in their temperature/viscosity behaviour: already more or less above the upper pumping limit viscosities rise abruptly and the oil suddenly becomes a stiff gel. This temperature is called the "pour point". Obviously it is most important for storage and transport and depending on the climate upper limits should be fixed between buyer and supplier.

4.5 WATER CONTENT

Heavy fuel oil as delivered to consumers can contain slight traces of water. In general, the water content is well below 0.5 % mass. The relatively small quantity of water found in heavy fuel oil is normally present in a finely dispersed form which does not cause corrosion or problems in storage, transport or combustion.

A water content higher than 0.5 % mass can be caused by water condensation in storage tanks which are not completely full or by leaks from pipes, steam or hot water heating coils. Excess water gradually collects on the floor of the tank together with other constituents of the oil or contaminants (e.g. sediments, dirt) and forms a sludge. Regular checks and proper care of the tanks are, therefore, necessary in order to prevent build up of sludge on the bottom of the tank.

Care must be taken to ensure that when oil is removed from the tank none of the sludge is allowed to get into the burner circuit as it may cause blocking of filters and other problems. In normal circumstances, heavy fuel oil tanks should be cleaned every two to three years.

Even if some water in the oil is not likely to cause any trouble in kiln operation etc. it still means less calorific value and must not be neglected when comparing fuel prices.

4.6 OTHER PROPERTIES

- ♦ calorific values 40 - 41 MJ/kg (see chapter 2.2)
- ♦ sulfur contents 1 - 3 % (see chapter 2.1)
- ♦ ash contents < 0.05 % (negligible for raw mix calculations)
- ♦ flash point:, >100°C (no danger of inadvertent or spontaneous ignition)
- ♦ carbon residue *) ~12 %

*) as measured by the Conradson test, i.e. heating of an oil sample with the exclusion of air until a solid residue of oil coke remains which is expressed in per cent mass of the oil sample. The procedure in this test, however, does not correspond to the conditions in a normal burner, where heavy fuel oil is first atomised into very fine droplets and is then burnt in suspension in an excess of air.

5. NATURAL GAS

The term "natural gas" is used to designate gases from below the surface of the earth. They consist of methane and higher paraffin's, nitrogen, carbon dioxide, hydrogen sulfide, and sometimes helium. In a narrower sense only combustible mixtures consisting predominantly of methane are called "natural gas".

Many natural gases, especially those from oil deposits, contain some natural gasoline, mainly paraffin's with 5 - 8 carbon atoms which are liquid at room temperature under atmospheric pressure. Depending on their gasoline content three types of natural gas are distinguished

- ♦ dry gas with < 10 9 gasoline per m³
- ♦ lean gas with 10 - 50 9 gasoline per m³
- ♦ wet gas with ; > 50 9 gasoline per m³

Before feeding the gas into the supply system it is purified. Especially the evil-smelling and poisonous hydrogen suphide which may amount to 15 % of the crude gas has to be eliminated. The valuable gasoline is also taken out and recovered.

Besides sulfur many other things which can cause trouble when employing liquid or solid fuels such as grinding, preheating, atomisation etc. do not exist with natural gas. Supervision of the fuel quality is scarcely necessary. Only the calorific value may vary somewhat mainly because of varying concentrations of inert compounds like CO^2. Abrupt changes of ±300 kJ/Nm³ have been reported. Therefore the installation of an on-line calorimeter is to be recommended which measures and records continuously the heating value of the gas.

Another disadvantage of gas is the low emissivity of the flame but owing to the dusty kiln atmosphere the heat transfer to the kiln charge is not as bad as might be apprehended.

6.   OTHER FUELS

Cement kilns offer the means and capacity to burn many kinds of combustibles. A large number of unusual "fuels" have already been tried in cement kilns, many of them successfully. Well known examples are oil shale, petrol coke, and used car tires. A lot more are listed in table 8 which can be considered as fairly comprehensive at the moment.

Table 8: By-product and waste fuels

SOLID		
Synthetic	**Vegetable matter or natural**	**Other**
waste tires (whole, Chips)	oil shale	domestic refuse
	coal wastes	refuse derived fuel (RDf)
rubber wastes	Low grade lignites	car shredding wastes
used battery casings	colliery benefaction rejects	oil Contaminated earth
plastic wastes	peat	
paper/Cardboard wastes	wood wastes	
fullers earth (from industrial oil preparation)	bark, wood chips	
	saw dust	
activated bentonite (from oil preparation)	rice husks	
	oil palm shells	
petrol coke (from refineries)	coconut shells	
graphite dust		
charcoal (wastes from steel industry)		

LIQUID	
Easy decomposable, low toxic	**Stable. toxic compounds (hazardous)**
tar (industrial by product)	poly-aromatic hydrocarbons (PAH)
acid tar	
sludge asphalt	polychlorinated byphenyls (PCB)
waste oils (from various sources)	chlorinated aromatics and alicyclics
oil sludge's	
solvents from paint industry	
petrochemical wastes	
chemical wastes (ketones, alcohol's, acetates, benzene. paint slurries)	

The motive behind these activities was not in the first place to save high grade fuel but the disposal of waste materials and industrial or agricultural by-products for which no other use could be found. Conventional disposal of such materials in open deposits or burning in refuse incineration plants is becoming increasingly difficult. It is costly and may lead to environmental hazards. This does not, or at least only partly, apply to the combustion in cement kilns for the following reasons:

♦ with flame temperatures around 2000°C all organic compounds, even the most resistant chlorinated hydrocarbons, are completely destroyed.

♦ most of the acid combustion products and the toxic trace elements are absorbed by the counter-current of raw meal. This natural cleaning process is very effective.

♦ the flue gases are very efficiently deducted. In modern cement plants the residual dust content is not rarely below 50 mg/Nm^3.

♦ Thus toxic trace elements which tend to accumulate in this dust are effectively retained and can be eliminated for controlled disposal.

♦ most of the toxic elements will be incorporated into the cement clinker where they can do no harm because their concentrations are very small and are further reduced in mortar or concrete (cement content only 10 - 15 % of concrete weight) where they remain fixed practically insoluble.

From the macro-economic point of view, too, the burning of waste and by-product fuels in cement kilns is by far preferable to deposition or combustion in special refuse incineration plants. However, not all fuels are suitable for cement kilns, or only to a limited extent. Some of the restrictions which have to be considered are :

♦ the concentrations of volatile elements like Cl and S must not exceed certain limits in order to avoid circulation or emission problems. In many cases the chlorine content of a fuel limits its possible input into the kiln to avoid circulation troubles. Excessive sulfur input can lead to harmful SO_2-emissions.

♦ the overall composition of the fuel ash should be such that it can easily be incorporated into the clinker without deteriorating its quality.

♦ some wastes may cause handling difficulties with regard to transport, storage, safety etc.

♦ the burning of waste fuels is usually subject to permission by local authorities. The plant has to prove that stack emissions do not exceed existing limitations which may turn out to be rather expensive.

All these points have to be taken into account when calculating the financial aspects. In many cases the expenses saved on high grade fuel will barely be sufficient to cover the extra costs. Even so a cement plant should consider that it can create goodwill and a favourable image in public by helping other people to get rid of their by-products and waste without impairing the environment.

It is clear from the foregoing that no general rules for the combustion of waste or by-product fuels can be given, each case being different from the next and having its own particular aspects. However, to illustrate the subject an example for the successful use of a waste the burning of old tires in cement kilns as practised in a German Cement plant shall be described.

The calorific value of tires is about 27 MJ/kg which is virtually the same as that of coal with an average mineral content and moisture. The tires are fed whole directly into a SP-kiln. The system begins with a forklift truck movement of tires from a storage pile onto a conveyor. This carries the tires up to an automatic balance. The tires having very different sizes weighing is indispensable to maintain a constant mass flow of the fuel. The number of tires fed per unit of time is automatically adjusted according to their weight. The tires enter the kiln via a chute and through an air lock to minimise heat loss into the transition chamber where temperatures are high enough to ensure complete combustion without any risk of environmentally negative aspects. The iron wires of the tires are oxidised to FeO which is incorporated into the clinker along with the coal ash. Of course, the raw mix has to be adjusted accordingly. Provided this is done the clinker quality will not be affected. Up to 20 % of the fuel has been replaced by old tires.